SPRAYDROP KINETIC ENERGY FROM IRRIGATION SPRINKLERS

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ABSTRACT. *Information on the drop energy from sprinklers is important for choosing the optimum sprinkler type for a particular soil. Drop size distribution data were collected for different types of sprinklers with various nozzle size-pressure combinations using a laser-optical method. Drop velocities were calculated using a trajectory model. The overall drop energy per unit of applied water was calculated. A method was developed to estimate the kinetic energy for a particular type of sprinkler with a given nozzle size and operating pressure using nozzle size and pressure head as independent variables. The volume mean drop size was found to be a good predictor of overall kinetic energy. With no wind, the overall drop energy varied from about 5 to 25 J/kg. The smooth plate spray head gave the least drop energy, while the single nozzle, impact-type sprinklers gave the greatest. Wind was found to increase drop energy by as much as a factor of three, but nozzle elevation had a small effect on drop energy.* **Keywords.** *Energy, Irrigation, Sprinklers.*

Sprinkler irrigation systems distribute water as discrete drops through the air. The range of sprinkler devices has increased dramatically in recent years, from conventional single or double nozzle impact sprinklers with various types of nozzles, to various types of deflection-plate sprinklers which can control the drop sizes and water distribution pattern over a wide range of flow rate and pressure.

Kinetic energy contained in water drops as they impact the soil surface affects soil erosion and infiltration processes. Bubenzer and Jones (1971) found that splash of several silt loam soils was approximately proportional to drop kinetic energy to the 1.5 power, and intensity to the 0.5 power. Kinnell (1982) found that, for sand, splash loss per drop varied with the square of the drop mass. Thompson and James (1985) found that the hydraulic resistance of the surface seal formed on a silt loam soil by impacting water drops increased with drop kinetic energy. Mohammed and Kohl (1987) found that infiltration rates on a loam soil decreased more rapidly as water was applied with increased kinetic energy per unit volume. Moldenhauer and Long (1964) found that infiltration rates decreased and soil loss increased as the energy in the applied water increased. Moldenhauer and Kemper (1969) noted how the shearing action of water drops removes soil particles from large clods, causing severe sealing and crusting in depressions on the soil surface. Kincaid et al. (1990) noted how reservoir tillage increases infiltration rates and surface storage initially, but gradually degrades in effectiveness as water drops impact and degrade the dikes and ridges. Crust formation due to drop impact is also a problem in seedling emergence of crops like sugar beets. These studies point out the importance drop sizes and drop energy on breaking down the soil surface aggregates. Although natural rainfall and crop cover can overshadow the sprinkler drop energy effects on a seasonal basis, in areas where crops are established primarily by irrigation, sprinkler drop energy can be important.

Existing sprinkler irrigation technology does not allow us to directly control drop sizes, so therefore, it is important to know the drop characteristics of a variety of sprinkler types in order to make intelligent choices in sprinkler system design. Several articles have been published describing the drop size distributions of specific types of sprinklers (Kohl, 1974; Kohl and DeBoer, 1984; Solomon et al., 1985; Kohl and DeBoer, 1990). Unfortunately, these data were collected using several different types of measurement methods, and some of the data may not be comparable, particularly in the upper and lower ends of the drop size spectra.

This article presents sprinkler drop energy calculations using a consistent set of drop size data collected by the laser-optical method (Kincaid et al.,1996). The objective was to determine the kinetic energy (volume weighted mean) from several types of sprinklers in order to develop a simplified method to estimate the drop energy for a given type of sprinkler.

METHODS AND THEORY

DROP SIZE DISTRIBUTION MEASUREMENT

A series of drop size distributions from several types of sprinklers were measured using laser-optical equipment described by Solomon et al. (1991). The instrument, a Particle Measuring Systems GBPP-100S, consists of a flat, horizontal laser beam 13 mm wide × 500 mm long, impinging on a detector array with 64 elements, 0.2 mm apart. The instrument measures drop sizes from 0.2 to 13 mm in 0.2-mm increments, and counts the number of

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drops in each size increment. The laser method has a tendency to oversize drops due to multiple drops passing through the laser beam simultaneously (Kohl et al., 1985). This problem was overcome by using a shield over the beam to reduce the effective window area to 13 × 100 mm (Kincaid et al., 1996).

The drop size distribution was measured at 2-m radial distance increments from the sprinkler for single nozzle sprinklers, and at 1-m increments for the spray heads whose pattern radius was less than about 8 m. A total of 10,000 drops were measured at each position except for the 12- and 14-m positions for large radius sprinklers where, to save time, only 4,000 drops were measured. Individual position distributions were then combined into an overall distribution for each sprinkler-nozzle-pressure combination by weighting them according to the fraction of the total water volume falling within each interval. The radial application rate pattern was measured on a 0.5-m grid with 100-mm-diameter catch containers. The nozzle height above the collectors and laser instrument was 0.7 m for the impact sprinklers, which have a nozzle angle of about 23°, and 3 m for the spray heads which emit water nearly horizontally. The spoon spray from the drive arm of the impact sprinklers was included in the drop size distributions.

A characteristic of the laser method is that drops are measured as the maximum in-flight drop width measured horizontally as the drops fall through the laser beam, and distorted drops sometimes gave unreasonably large diameters. Green (1975) reviewed previous work on the shapes of large raindrops and concluded that, although these drops were typically in a state of oscillation, on average they could be represented by oblate spheroids. Beard (1976) quantified the shape deviation with the relationship:

$$D_m/D_0 = 0.973 + 0.027\,D_0 \tag{1}$$

where D_m is horizontal projected diameter (mm) and D_0 is equivalent spherical diameter (mm).

Equation 1 was used to adjust the laser drop size data for distortion ($1 < D_0 < 7$ mm). The oil-photographic method of Eigel and Moore (1983) was used as a check on the laser method, both at the smallest drop sizes (< 0.2 mm) and at large sizes to check the distortion relationship above. Drops were counted in 0.2-mm-diameter increments as in the laser method. The adjusted laser data agreed well with the data from the oil-photographic method (Kincaid et al., 1996).

Drop Trajectory and Velocity Modeling

The analysis used is substantially the same as that described by Seginer (1965), von Bernuth (1988), and Vories et al. (1987). A drop trajectory model was developed as part of the drop evaporation modeling work reported by Kincaid and Longley (1989). Drop trajectories were computed by the equation of motion:

$$\rho_d(\pi/6)D^3\,dV/dt =$$

$$(\pi/6)D^3 g(\rho_d - \rho_a) - C_D(\pi/8)D^2\rho_a V_r^2 \tag{2}$$

where

D = drop diameter (m)
V = drop velocity (m/s)
V_r = drop velocity relative to air (m/s)
ρ_d = drop density (kg/m^3)
ρ_a = air density (kg/m^3)
C_D = drag coefficient
g = acceleration of gravity, 9.81 m/s^2
π = 3.1416

The drag coefficient, C_D, is assumed to be a function of the Reynolds' number:

$$R_e = DV_r/v \tag{3}$$

where v is the kinematic viscosity of air (m^2/s).

The drag coefficient-Reynold's number relationship is described by Park et al. (1982, 1983) who analyzed the data of Laws (1941) and Gunn and Kinzer (1949), and found that the drag coefficient decreases as R_e increases up to about 1000, and then increases due to deformation of the larger water drops. For $R_e \le 1000$:

$$C_D = (24/R_e)\,(1 + 0.15\,R_e^{0.687}) \tag{4}$$

For $R_e > 1000$, the following equation was used:

$$C_D = 0.438\,\{1.0 + 0.21\,[(R_e/1000) - 1]^{1.25}\} \tag{5}$$

The mean density at a particular location was determined by:

$$\rho_a = 16.019\,\{EXP[-(724.3 + T_a)/287.8]\}$$

$$\times (1 - 0.00002257\,E)^{4.2553} \tag{6}$$

where E is the elevation above sea level (m) and T_a is the air temperature (°C).

The kinematic viscosity of air is:

$$v = 0.000001087\,T_r^{1.5}/[\rho_a(T_r + 198.6)] \tag{7}$$

where T_r(°R) = 1.8 T_a + 491.67.

Water is emitted from sprinkler nozzles at a velocity determined by the nozzle pressure:

$$V_j = (2\,P_n)^{0.5} \tag{8}$$

where V_j is jet velocity (m/s) and P_n is nozzle pressure (kPa).

These model equations were evaluated by using data from Hinkle et al. (1987) who measured drop fall velocities at 1,570-m elevation and air temperature of 20°C. Fall velocities for the drop sizes and air conditions from Hinkle et al. (1987) were computed and compared (table 1) with fall velocities measured by Hinkle et al. (1987). A correlation between measured and calculated velocities from table 1 gave an R^2 value of 0.999, and standard error of 0.058 m/s. Computed values of the Reynolds' number are given for reference.

As drops travel through the air, the relative vertical velocity approaches a terminal fall velocity, and horizontal velocity approaches the air velocity. Immediately after leaving a nozzle, the drops travel as a larger mass (drops actually form as the mass breaks up), and thus experience

Table 1. Model computed fall velocities compared with measured velocities from Hinkle et al. (1987), for drops falling from rest in still air at 20°C, and atmospheric pressure at 1 570-m elevation

Drop Diameter (mm)	Fall Height (m)	Measured Velocity (m/s)	Calculated Velocity (m/s)	Reynolds' No.
2.4	0.5	2.97	2.97	380
2.4	2.0	5.35	5.33	700
2.4	5.0	7.09	7.13	960
3.8	0.5	3.02	3.03	620
3.8	2.0	5.68	5.72	1200
3.8	5.0	7.87	7.90	1690
5.2	0.5	3.04	3.05	860
5.2	2.0	5.85	5.83	1680
5.2	5.0	8.33	8.18	2400

reduced air drag. For purposes of computing drag, the relative velocity, V_r, was multiplied by the factor:

$$F = (0.1 + 0.9\ d/d_D) \text{ for } d < d_D$$

$$\text{and } F = 1.0 \text{ for } d \geq d_D \qquad (9)$$

where d is distance from the nozzle (m) and d_D is an empirical distance parameter (m).

The parameter d_D was evaluated by comparing the computed travel distance for the largest few drop sizes with the measured pattern radius. For single nozzle sprinklers, the optimum value of d_D was about 15% of the measured pattern radius, and for spray heads, about 5%. Although the the value of d_D can have a considerable effect on pattern shape, for the purpose of computing drop energy it is not very critical.

The spray heads tested use an impingement plate to deflect the jet and control pattern shape and drop sizes. This plate reduces the velocity of the water, and the actual initial trajectory velocity, V_i, is less than the nozzle jet velocity. This effect was measured by using a pressure gauge and pitot tube in the nozzle jet, and in the stream leaving the plate. For the flat-plate spray head, the velocity reduction ratio, V_i/V_j, was related to the ratio of nozzle diameter to plate diameter, D_n/D_p. For $D_n/D_p < 0.3$, $V_i/V_j = (D_n/D_p)/0.3$, and for $D_n/D_p > 0.3$, $V_i/V_j = 0.97$. For grooved-plate spray heads and other devices which use a curved deflector, $V_i/V_j = 0.97$, for all ratios D_n/D_p. The initial velocity reduction has very little effect on final drop velocity and could be ignored in this analysis.

Drop Kinetic Energy

The trajectory model was used to compute the velocity at impact for each drop size category from 0.2 to 8 mm in 0.2-mm increments. The unit kinetic energy of each drop size was then calculated as:

$$E_d = V_0^2/2 \qquad (10)$$

where E_d is drop kinetic energy per unit mass (J/kg) and V_0 is drop velocity at zero elevation (m/s).

The overall drop energy was computed by weighting the unit kinetic energy for each drop size by the fraction of total volume in each drop size. The kinetic energy reported here is the mean volume weighed kinetic energy for the entire wetted area of the sprinkler. No attempt is made to describe the variation of kinetic energy with distance from the sprinkler. Drop sizes and energy are larger near the periphery of the pattern. However, in a normal field situation, sprinkler patterns overlap so that the energy flux rate is nearly uniform except at the edge of a single lateral pattern where the drops tend to be larger. Also, wind effects tend to erase any effects due to the radial energy distribution pattern.

Wind effects were modeled assuming a uniform wind velocity profile. A logarithmic velocity profile was also tried. It was found that the total drop energy was affected very little by the wind profile assumption due to the momentum of the large drops, which contain most of the kinetic energy. The effect of initial horizontal trajectory angle on impact energy was averaged by combining the impact energy from drops emitted from the nozzle upwind, downwind, and perpendicular to the wind for each drop size.

The individual tests are listed in tables 2 and 3 for impact sprinklers and spray heads, respectively. The nozzle size and pressure, along with the mean volumetric drop size, d_{50} percent volume in drops larger than 3 mm and the overall drop energy are given. Both the drop sizes and the drop energy tend to increase with an increase in nozzle size and decrease with increasing nozzle pressure for a given type of sprinkler and nozzle. The effective nozzle diameter was calculated from the pressure and nozzle flow rate rather than using the actual nozzle diameter, so that square nozzles and flow control nozzles could be included.

The R parameter is comprised of the effective nozzle diameter (mm) and pressure head (m of water), as defined below. For each type of sprinkler, the overall energy was plotted against the R values, as shown for example in figure 1 for impact sprinklers with round nozzles. Flow control nozzles gave energies very similar to the straight bore nozzles and were included with the small nozzle

Table 2. Pressure, nozzle size, d_{50} drop size, percent large drops, and energy per unit mass for impact sprinklers

Test	Pressure (kPa)	Nozzle (mm)	d_{50} (mm)	> 3 mm (% vol)	Energy (J/kg)
1	137	3.04	2.52	44.7	19.10
2	274	3.08	2.00	27.1	17.43
3	402	2.96	1.32	5.0	12.38
4	402	3.46	1.32	4.2	12.44
5	206	3.73	2.51	40.2	20.00
6	304	3.86	1.57	11.2	14.57
7	402	3.77	1.30	0.7	12.18
8	499	3.70	1.16	0.8	10.85
9	411	5.44	1.40	6.0	13.33
10	548	5.45	1.19	2.5	11.39
11	206	9.30	2.87	49.9	21.91
12	411	9.33	1.73	16.9	16.55
13	617	9.34	1.70	16.3	16.84
14	206	12.23	2.84	48.8	21.71
15	617	12.23	1.74	11.1	16.79
16	206	15.02	2.76	45.4	21.77
17	411	15.05	1.83	16.7	17.68
18	206	3.83	2.76	45.1	21.24
19	411	3.43	1.45	10.0	13.85
20	206	4.19	2.90	51.0	21.59
21	274	4.07	2.30	34.8	19.34
22	411	3.80	1.25	2.5	11.67
23	206	3.44	1.54	16.3	14.18
24	137	3.81	1.89	32.9	15.98
25	206	3.84	1.97	27.3	17.01
26	274	3.87	1.51	14.6	14.26
27	206	4.17	2.03	30.2	17.34

Table 3. Pressure, nozzle size, d_{50} drop size, percent large drops, and energy per unit mass for spray heads

Test	Pressure (kPa)	Nozzle (mm)	d_{50} (mm)	> 3 mm (% vol)	Energy (J/kg)
28	69	3.12	1.77	18.5	13.50
29	137	3.16	1.21	2.7	10.36
30	274	3.16	0.86	0.0	7.17
31	69	6.24	2.34	37.6	16.44
32	137	6.22	1.60	12.2	13.62
33	274	6.24	1.18	0.4	10.22
34	69	3.13	1.55	13.8	12.18
35	137	3.13	1.47	15.9	12.81
36	274	3.12	0.86	0.0	6.98
37	69	6.30	2.53	43.7	16.97
38	137	6.37	1.55	10.6	13.11
39	274	6.30	1.27	2.1	11.20
40	108	4.62	3.07	52.9	23.75
41	206	4.63	2.02	32.2	19.42
42	108	6.16	2.48	39.3	21.45
43	206	6.22	2.00	30.2	19.26
44	313	6.22	1.26	5.1	13.10
45	108	4.63	1.83	27.7	17.83
46	206	4.63	1.18	9.4	12.64
47	108	6.16	1.63	25.2	16.38
48	206	6.22	1.23	11.8	13.24
49	206	9.24	1.38	8.9	14.34
50	108	4.62	1.32	7.8	13.55
51	206	4.63	1.15	2.3	11.28
52	108	6.12	1.55	19.7	15.62
53	206	6.16	1.05	2.5	10.64
54	69	3.09	0.85	0.0	7.02
55	206	3.12	0.76	0.0	6.14
56	69	6.12	1.23	0.0	11.98
57	206	6.25	1.16	0.0	11.75
58	69	8.10	1.61	20.2	16.13
59	206	8.19	1.38	5.1	14.65
60	69	3.09	1.19	0.0	10.66
61	206	3.13	1.09	0.0	9.73
62	69	6.16	1.68	4.6	16.42
63	206	6.25	1.98	19.7	20.16
64	69	7.76	2.34	28.3	21.83
65	206	7.85	2.03	26.0	20.65
66	69	2.98	0.70	0.0	5.35
67	108	3.06	0.70	0.0	5.58
68	206	3.07	0.68	0.0	5.35
69	69	4.57	0.94	0.3	8.84
70	206	4.61	0.86	0.2	7.54
71	69	6.12	1.08	1.4	10.57
72	108	6.12	1.21	2.3	12.36
73	206	6.22	1.03	0.5	10.27
74	69	9.06	1.63	16.8	16.47
75	206	9.15	1.31	6.0	14.00

impacts. A linear regression was run on each plot. A linear equation relating energy to R is of the form:

$$E_k = e_0 + e_1 R \quad (11)$$

where E_k is overall drop energy (J/kg) and e_0 and e_1 are regression coefficients.

The parameter R is defined as:

$$R = D_n{}^e / H^f \quad (12)$$

where

D_n = nozzle diameter (mm)

H = nozzle pressure head (m) (1 m of water is equivalent to 9.8 kPa)

e and f = constants

Values of the coefficients are listed in table 4 for the 10 types of sprinklers, using e = f = 1. The separate regression

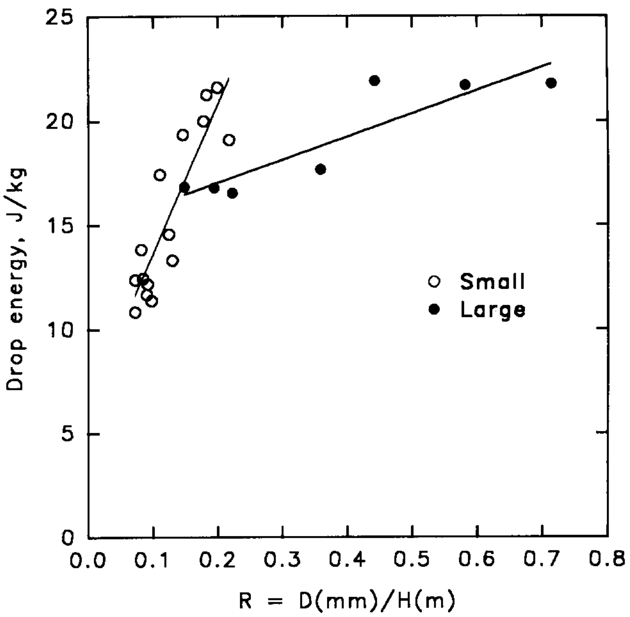

Figure 1–Drop energy related to R value for impact sprinklers with small (3 to 6 mm) and large (9 to 15 mm) round-orifice nozzles.

lines are shown in figure 2 for comparison, showing the range of data plotted. There appears to be an upper limit of about 20 to 25 J/kg in the overall drop energy from sprinklers with no wind. This is due to the upper limit on drop sizes discussed in Kincaid et al. (1996). Figure 2 gives an overall comparison between the different types of sprinklers, but the energy estimates for some types can be improved by varying the exponents e and f to give more or less emphasis to the nozzle size relative to pressure head. The round nozzle impacts and the rotators gave improved correlations with e = 0.5 and f = 1, and the results are given in table 5. Figure 3 shows the data plotted for the rotator. The spray heads including the smooth plate, medium groove, and LDN multiple grooved-plates better correlated with R when e = 2 and f = 0.5 (table 6). The reason for these improved fits is that for the single nozzle sprinklers the drop sizes are affected more by the pressure, whereas for the spray heads the drop sizes are controlled primarily by the nozzle size (see Kincaid et al.,1996). The poor fit for the square (CD) nozzles is due to a limited range of data and no attempt was made to improve it.

The nozzle elevations (height above soil surface) used in the energy calculations in tables 2 and 3 were 1 m for the impact sprinklers and 3 m for the spray heads. Other

Table 4. Coefficients for estimating energy from 10 sprinkler types, using the parameter R = d(mm)/h(m) with equation 11

Type		Tests	Intercept e_0	Slope e_1	r
1.	Impact, large round nozzles	11-17	14.8	11.1	0.90
2.	Impact, small round nozzles	1-10, 18-22	6.5	71.6	0.89
3.	Impact, square nozzles	23-27	13.1	13.7	0.47
4.	Rotating plate, 4 groove	40-44	13.1	18.7	0.71
5.	LDN, Senninger	60-65	12.9	6.8	0.48
6.	Rotating plate, 6 groove	45-49	10.2	12.2	0.74
7.	Spinning plate, 6 groove	50-53	7.3	14.7	0.95
8.	Wobbler, Senninger	28-39	7.9	10.6	0.91
9.	Spray, medium groove plate	54-59	7.5	6.9	0.66
10.	Spray, smooth flat plate	66-75	5.5	8.0	0.72

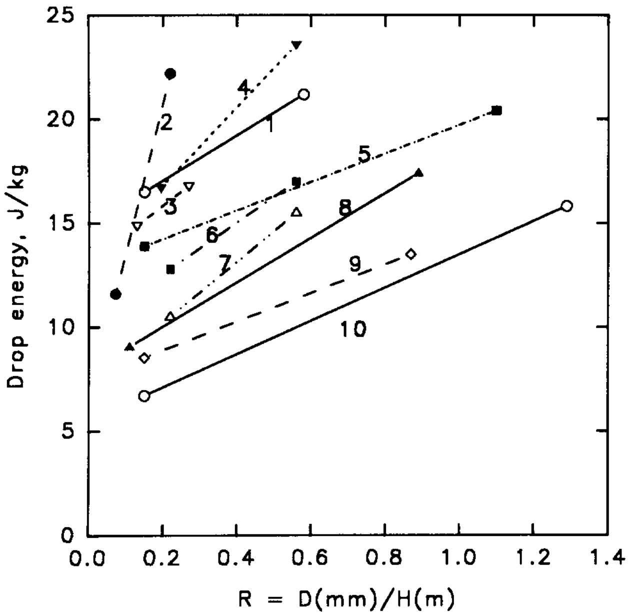

Figure 2–Effect of nozzle/head parameter R on drop energy for all types (points are regression line endpoints) 1 = large nozzle impact, 2 = small nozzle impact, 3 = square nozzle impact, 4 = rotator, D4 plate, 5 = LDN, 6 = rotator, D6, 7 = rotator, D6 spinner, 8 = wobbler, 9 = spray, medium groove plate, 10 = spray, flat smooth plate.

Table 5. Coefficients for estimating energy from impact sprinklers sprinklers and rotators using the parameter R = d(mm)$^{0.5}$/h(m) with equation 11

Type	Tests	Intercept e_0	Slope e_1	r
1. Impact, large round nozzles	11-17	14.1	45.1	0.96
2. Impact, small round nozzles	1-10 & 18-22	6.9	132	0.88
4. Rotating plate, 4 groove	40-44	12.1	50.7	0.81
6. Rotating plate, 6 groove	45-49	8.9	38.0	0.90
7. Spinning plate, 6 groove	50-53	6.9	36.9	0.96

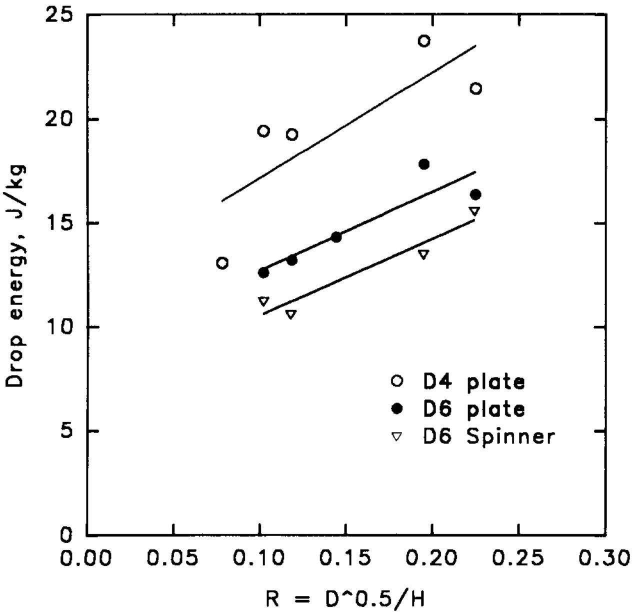

Figure 3–Effect of R parameter on drop energy for rotators (with e = 0.5, f = 1).

Table 6. Coefficients for estimating energy from sprayheads using the parameter R =d(mm)^2/h(m)$^{0.5}$ with equation 11

Type	Tests	Intercept e_0	Slope e_1	r
5. LDN, Senninger	60-65	10.4	0.57	0.83
9. Spray, Medium groove plate	54-59	6.2	0.45	0.94
10. Spray, Smooth flat plate	66-75	5.4	0.40	0.94

elevations were simulated, and two examples are shown in figure 4. For the spray heads, nozzle elevation had little effect on drop energy, but a minimum energy was reached at about a 2-m elevation where the initial jet velocity is dissipated, but the drops had not yet reached terminal velocity. The overall energy for the impact head increased about 30% as elevation increased from 1 to 6 m. Sprinkler types with high energy have larger drops which require longer fall distances to approach terminal velocity. The actual fall height of drops from the impact heads is about 2 m greater than the nozzle height.

The impact energy increased significantly as the simulated windspeed increased (fig. 5). This is because the horizontal velocity component increases with windspeed, and the total velocity at impact with the surface was used to compute energy. It appears that wind can increase the energy by a factor of 2 or 3. As an approximation, the energy with wind can be estimated by:

$$E_w = E_k + W^{1.5} \tag{13}$$

where E_k is the energy with no wind (J/kg) and W is windspeed (m/s).

The drop energy was correlated with mean volumetric drop size and % > 3 mm for all data, with d_{50} having the better correlation coefficient. These relationships appear to be independent of sprinkler type, and the best fit equations are:

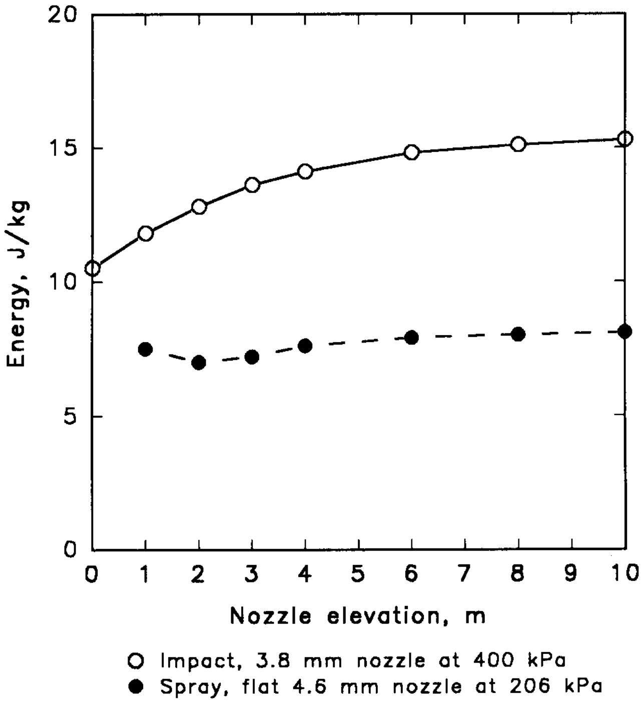

Figure 4–Effect of nozzle elevation on droplet energy for two sprinkler-nozzle pressure combinations (no wind).

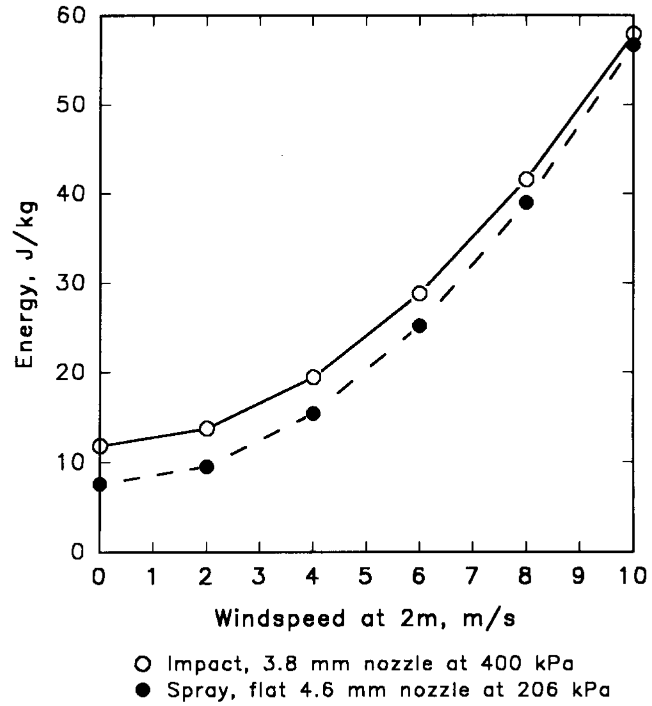

Figure 5–Effect of windspeed on droplet energy for two sprinkler-nozzle pressure combinations.

$$E_k = 2.79 + 7.2\, d_{50}\ (r = 0.94) \tag{14}$$

and

$$E_k = 10.41 + 0.249\ (\% > 3\ \text{mm})\ (r = 0.88) \tag{15}$$

Discussion

The relationships presented here to estimate drop energy can be used to help select the most suitable type of sprinkler for particular climate, soil, and crop conditions. The designer must weigh the effect of drop impact against other factors such as wind drift and evaporation, and the probability of high-intensity rainfall. The relationships may be useful, for example, in designing center pivot systems with dual sprinkler packages with small-drop sprinklers for bare soil irrigation, crop establishment, and chemical application, and a large-drop package for irrigation with full crop cover. Moldenhauer and Kemper (1969) found that the infiltration rate on several soils decreased by approximately one order of magnitude when cumulative drop energy per unit area totaled 500 J/m^2. Using small-drop sprays applying 5 J/kg, approximately 100 mm of water could be applied before this threshold is reached (1 kg = 1 mm × m^2); whereas, with large drops applying 20 J/kg, only 25 mm could be applied without a large reduction in infiltration rate.

For round orifice nozzles, the small (3 to 6 mm) nozzle impact sprinkler gave a different relationship than the large (9 to 15 mm) nozzles. The small nozzle relationship tends to approach zero energy as R approaches zero, and the large nozzle relationship approaches the upper limit at large R values.

Conclusions

Considering the range of data in figure 3, the energy from the sprinklers tested varies by about a factor of 5. The relationships given in tables 4 to 6 should be sufficiently accurate to estimate the energy from most sprinklers. The effect of wind should be considered, particularly at windspeeds above 5 m/s. The effect of nozzle elevation can usually be ignored with spray heads, but with impact sprinklers, the energy should be increased about 5% per meter of elevation above 1 m up to 6 m. Drop energy can be estimated from the mean volumetric drop size if the drop size distribution for a particular sprinkler-nozzle-pressure combination is known.

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